

The Pierre Auger Observatory

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Abstract

One of the most fascinating puzzles in particle astrophysics today is that of the origin and nature of the highest energy cosmic rays. The Pierre Auger Observatory (PAO), currently under construction in Province of Mendoza, Argentina, and with another site planned in the Northern hemisphere, is a major international effort to make precise, high statistics studies of the highest energy cosmic rays. It is the first experiment designed to work in a hybrid mode incorporating both a ground-based array of 1600 particle detectors spread over 3000 km² with fluorescence telescopes placed on the boundaries of the surface array. The current status of the observatory is presented and prospects for the future discussed.

I. INTRODUCTION

The observation of ultra high energy cosmic rays (UHECR) with energies above 10^{20} eV [1], is puzzling in at least two ways. First of all, it is quite difficult to conceive of acceleration mechanisms which are adequate to impart such enormous energies to cosmic ray particles[2, 3] – energies comparable to those carried by everyday objects like tennis balls or golf balls! Secondly, even if such a mechanism is found, it is difficult to see how such high energy particles would make it through the background radiation: the celebrated GZK cutoff[4] predicts that protons over about 5×10^{19} eV should rapidly lose energy in inelastic collisions with the cosmic microwave background photons with similar energy degradation mechanisms being present for most other particles, including heavy nuclei.

A very important point to make early in this talk is that while there is a puzzle concerning so-called “super-GZK events”, the Pierre Auger Observatory will provide interesting information regardless of how well the GZK cutoff holds out. If there is no GZK cutoff, this will be an unambiguous sign of new physics. If the GZK cutoff is found, then we can rest assured of that piece of the physics and confidently use the data to try to understand the nature of the sources. This point is often missed by people who see the whole physics motivation as “is there a GZK cutoff or not?”.

Above 10^{15} eV, cosmic ray primaries are not detected directly, but rather through the effects that such particles produce when they strike the upper atmosphere. There they initiate a cascade of reactions, some nuclear, but most forming an electromagnetic shower made of repeated bremsstrahlung and e^+e^- pair creation events. This shower can be detected experimentally through the fluorescence it produces in the atmosphere (due to excited nitrogen) or via the particles that reach the ground.

Our understanding of the highest energy part of the spectrum above the so-called “ankle” (5×10^{18} eV) is poor due to a combination of low statistics, uncertain energy resolution, uncertainties in energy conversion arising from models, and a lack of knowledge of the mass composition and the fluorescence yield efficiency. Clearly there is something interesting going on, but to fully understand the situation we need more statistics, better control over systematic uncertainties, and full sky coverage: enter the Pierre Auger Observatory. A comprehensive review of the state of the art prior to the Pierre Auger Observatory can be found in [5].

II. THE PIERRE AUGER OBSERVATORY

The Pierre Auger Observatory (PAO) is actually comprised of two sub-observatories, one currently under construction in Mendoza, Argentina since 2000. This site is especially interesting, since in addition to being in the wine-growing district, it offers a view of the centre of the galaxy. Another is planned for the Northern hemisphere, and while for the remainder of this talk I will concentrate on the Southern site it is important to understand that the full observatory is comprised of two sites. This will eventually allow full-sky coverage which is very important to allow good studies on anisotropies[6].

The PAO is designed to measure the energy, arrival direction and primary species with excellent precision and very high statistics. A unique feature of the design is the combination of both fluorescence detection and ground-based particle detectors which can be operated independently as well as together in “hybrid” mode.

The scale of the observatory was determined by the requirement that we can collect high

statistics in and around the region of the expected GZK cutoff, with 1600 particle detectors separated from each other by 1.5 km and covering an area of 3000 km², overlooked by four fluorescence detectors which can only operate when ambient conditions offer a clear, dark sky, which leads to a roughly 10% duty cycle. Figure 1 shows, together with one of the surface detectors, a photograph of one the fluorescence detectors where both the mirror and the box of 440 photomultipliers which register the fluorescence light can be seen. The fluorescence measurements are complemented by a very comprehensive atmospheric monitoring system. The surface array stations are water Čerenkov detectors and can operate continuously.

The fact that about 10% of the showers detected by PAO will be observed by *both* surface and fluorescence detectors, offers the possibility of doing calibrations and understanding systematic errors in a manner that has never been possible before. Access to a large-dimensional parameter space of observables should allow not only determination of the direction and energy of incoming primaries, but also the disentanglement of information about composition from the notoriously difficult systematic errors associated with the choice of hadronic interaction models.

Each ground-based detector is a cylindrical, opaque tank of 10 m² and a water depth of 1.2 m, where particles produce light by Čerenkov radiation. The filtered water is contained in a bag which diffusely reflects the light collected by three photomultipliers (PMT's) installed on the top. The large diameter PMT's (≈ 20 cm) are mounted facing down and look at the water through sealed polyethylene windows that are integral part of the internal liner. The signals are processed locally and a second level trigger is identified before transmitting the data to the central acquisition system [7]. The fact that the tanks are quite deep enables showers to be detected efficiently over a wide angular range. Due to the size of the array, the stations have to be able to function independently and yet in communication with the central data acquisition system. The stations operate on battery-backed solar power and communicate with a central station by using wireless LAN radio links [8]. Absolute timing information is obtained from the Global Positioning System (GPS) [9] and is used to reconstruct the direction from which the primary came. Figure 1 shows a water Čerenkov detector installed in the Southern Observatory as well as one of the fluorescence detectors. Mounted on top of the tank are the solar panel, electronic enclosure, mast, radio antenna and GPS antenna. The battery is housed in a box attached to the tank.

The expected angular resolution for the ground array of the Southern Auger Observatory is less than 1° for all energies, and better for large events above 10²⁰eV. The expected energy resolution is estimated to be 12%, averaged over all energies (assuming a proton-iron primary mixture), falling to 10% at 10²⁰eV. The limiting aperture for the full Southern Observatory array and for zenith angle less than 60° is 7350 km²sr. The detection efficiency at the trigger level should reach 100% for energies above 10¹⁹eV [10]. Additionally, if events above 60 degrees can be analyzed effectively, the aperture will increase by about 50% .

In hybrid mode, the Pierre Auger Observatory is expected to have 6% energy resolution and an angular precision of 0.5° at 10²⁰eV where only statistical errors are taken into account in these estimates. The detector is optimized for energies above 10¹⁹eV, with good reconstruction expected at energies down to 1 EeV. The hybrid data set will provide the best evaluation of primary species, allowing a simultaneous fit to all parameters sensitive to mass composition.

The first cosmic ray event detected by one of the two prototype telescopes installed at Los Leones is displayed in Figure 2. A twenty pixel track, produced by light from a shower, with a length of 8 μ s can be seen. The angular velocity of the shower image across the sky



FIG. 1: Photographs of a typical surface detector and one of the fluorescence detectors showing the mirrors and the array of phototubes onto which they direct the collected light.

allows the distance of the shower core to be established as 5 km. The time duration of the signal in the field of view of the telescope corresponds to a track length of 2.4 km. The mirror inverts the image, and particles from the sky appear to be going upwards as seen by the camera.

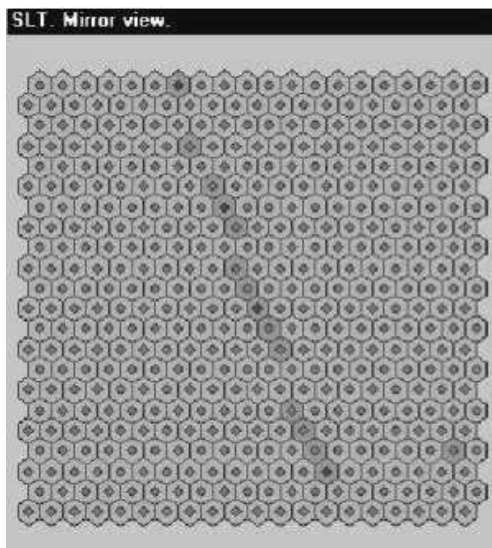


FIG. 2: First high energy cosmic ray observed by one of the prototype telescopes at Los Leones.

Construction continues, and we look forward to the large amount of very high quality which will appear in the years to come, and the light it will shed on one of nature's great mysteries.

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